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TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 399

DURALUMIN WELDING

By Lieut. Comdr. Wm. Nelson, (CC), U.S.N.

From "Aviation," January 17, 1927

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

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DURALUMIN WELDING.*

By Lieut. Comdr. Wm. Nelson, (CC), U.S.N.

General

The methods of joining metallic materials available to the aircraft builder are either mechanical or thermal in nature. The thermal means embrace forge welding, gas welding, electric welding, soldering and brazing. All of these involve the partial or complete melting of metals similar to or different from the parts being joined. Forge welding and electric resistance welding do not require the use of any welding rod; whereas, all the others depend in whole or in part on the addition of a fused rod.

It is natural that all methods of joining steels have been tried on aluminum and its alloys. Unfortunately, the high thermal conductivity of aluminum and the presence of the oxide film on this metal has precluded the adoption of most of the thermal means of uniting. Welding aluminum alloys by forging appears to be so impracticable that it is doubtful if that means will ever be used. The oxide film which forms on aluminum alloys is so difficult to eradicate that forge welding remains in search of a method. Gas welding is the most successful of all of the melting

* From "Aviation," January 17, 1927.

processes and is covered in detail below. Electric welding of aluminum and duralumin is possible but considerable investigation must be done before this means can be considered to be of use outside of the laboratory. Soldering of this metal has been worked on in laboratories from time to time, but that too is still of too experimental a nature to be used in any production job. Brazing duralumin has not had sufficient demand to make any extensive experiments advisable.

In a broad sense, if welding were completely satisfactory, it could be used to advantage in joining many parts of all-metal aircraft which are now riveted. In a contracted sense, it could be used only in places where riveting is not cheaper. However, due to the elements of strength, resistance to corrosion, limited fatigue data, and such, the welding of aluminum in aircraft construction has been limited to repairs, manufacture of tanks, manufacture of cowling, etc., and to special non-strength features. Nevertheless, aircraft builders are presented with additional flexibility if the welding of aluminum alloys is within the capabilities of their shops; so, although still experimental in many ways, the use of this light metal in airplanes brings with it a need for knowledge of this subject.

Electric Welding

Resistance welding is commonly known as electric "butt" or "spot" welding. In this process the junction is made by allowing a large current of low voltage to flow through the place to be fused.

Electric butt welding of aluminum or duralumin is not known. Electric spot welding seems to present certain features which have practical application. A complete study has not yet been made, but considerable preliminary work on spot welding duralumin sheet in an automatic steel welding machine indicates that it can be done with a fair degree of success. In some work done recently, the spots were about $3/32$ inch in diameter, with a tenacity in tension equal to about 500 pounds per spot. Failure occurred by having a spot pull out of the sheets. The metal in the welds appeared to be burned; cracks, pits, and irregularities being the rule. Corrosion tests conducted on samples did not confirm conclusively an opinion that corrosion would concentrate in or near the point of weld. Some samples corroded did show a tendency towards electrolytic action between the metal in the spot and the sheet itself, but it was not general.

Electric arc welding consists of using an electric arc to fuse the junction and the filler rod. An electrode of carbon acts as one of the poles in the circuit and the material being welded as the other pole. By proper manipulation of the carbon electrode an arc is struck and furnishes the heat necessary to melt the filler rod and fuse that and the parts being welded. The temperatures produced in the arc are exceedingly high and for that reason this method of welding is not conducive to good results where aluminum and duralumin are concerned.

Soldering

No success seems to have been had in using soft solders with aluminum. This is perhaps due to the failure to break down the oxide film on the basic metal by the relatively small amount of heat applied. Silver solders produce better results on the whole, but so far, solders sufficiently satisfactory to even produce a joint are not generally available. The plating of the aluminum alloy parts to be soldered seems to be a necessary part of the operation, in which case practically any solder will adhere to the plate if the plate will adhere to the aluminum concerned. The value of soldering is reduced further by the corrosion factor. Electrolytic action takes place in the vicinity of soldered joints, so that corrosion becomes a matter of serious concern in a location where everything should be done to avoid corrosion.

Gas Welding.

Gas welding aluminum and duralumin is the one that presents the greatest actualities and possibilities in the aircraft industry. Gas welding in an atmosphere other than air may become a matter of general interest later on; but at the present time fusion-joining in air is the more feasible and practical. This particular means employs acetylene and oxygen or hydrogen and oxygen to produce the heat necessary to fuse the metal to be joined. Experience and the size of the material determine whether hydrogen or acetylene shall be used on a job of aluminum or

duralumin welding. With relatively thick sheets it is necessary to use acetylene to get the required heat; whereas, with very thin sheets, hydrogen serves to better advantage by tending to prevent burning.

In general, aluminum sheet and aluminum castings are easier to weld than duralumin. All of these metals have a low melting point with a very small working range of temperature and a great deal of skill is required to produce satisfactory results. The weld as a rule is of a cast structure and contains the properties of that material, being brittle and subject to fatigue failure. In duralumin the material next to the weld is affected by the heat applied changing the physical properties to a material extent. Buckling, cracking and burning are more likely to occur in welding duralumin than in welding aluminum, due perhaps to the changes set up in the surrounding metal by the heat of the torch.

Gas welding of aluminum has not been undertaken with any great degree of confidence by the aircraft industry as a whole. The reasons given are various, but in the main, it is believed that this lack of interest is due primarily to the difficulties encountered in the making of the welds. With that in mind, most of that which follows consists of notes on the design of parts to be welded and the actual making of the weld in aluminum alloys.

First, there are certain design features which are very im-

portant in any work involving duralumin welding. Heat-treated specimens of gas-welded duralumin show a tensile strength of about 30,000 lb. per sq.in., with an elongation of 1.5% to 5% in 2 inches. Heat treating the samples raises the tensile strength to about 40,000 lb. per sq.in., with no changes in the elongation. Welded duralumin heat-treated and with dressed joint has an efficiency of 25% to 80% (55,000 lb. per sq.in.). So much for the figures. But to insure satisfactory results, the designer must also apply interest to the operation, and the following points are material in that respect:

- (1) Make all welds as simple and as accessible as possible;
- (2) Reduce intersections of welds to a minimum;
- (3) Provide for expansion and contraction around welds, by means of beads, grooves, dished heads, crowns, etc.;
- (4) Use sheet metal or tube fittings in preference to cast fittings;
- (5) Fittings should be set in and welded rather than being attached to the outside.

The equipment used for welding with either acetylene or hydrogen is essentially the same as is used for light gauge steel excepting that a lead-burner's torch is used in welding the aluminum alloys. The heat conductivity of aluminum is high, so a large torch results in a lack of concentration with consequent jagged and unsightly welds. The small torch demands a smaller hose than the regular full size welding torch, which in turn necessitates a reducing valve block. Other than that, the equip-

ment is not different from the ordinary gas welder's outfit.

Filler rod employed in welding any of the aluminum alloys is usually of the same material as the parts being joined. Where one or both parts are aluminum, commercial soft-annealed, pure aluminum wire $1/16"$ to $1/18"$ diameter is used. The welding rod for castings is an 8% copper aluminum alloy wire. Strips sheared from the edge of sheets serve very well for welding rod, and give a material of the correct chemical composition.

The fluxes used in aluminum alloy welding seem to be a constant source of question. Many kinds of fluxes are available in the markets with perhaps as many kinds of opinions regarding their relative merits. The principal objections to most aluminum fluxes are that they are too hygroscopic, causing a short life, or that the melting point is too high or too low, causing burning of the metal or of the flux.

The following flux has been subjected to experiment and to shop use and should meet most of the airplane builder's needs:

Sodium chloride,	32%	by weight,
Sodium fluoride,	20%	" "
Potassium chloride,	24%	" "
Lithium chloride,	24%	" "

This flux produces a sound, clean, uniform weld and permits welding at a more rapid rate than most other compounds will allow. The corrosive action of fluxes cannot be taken into consideration in comparing their relative merits, for all are more

or less hygroscopic and accordingly, active agents in inducing corrosion in duralumin. The merits of the fluxes must be based on the results obtained by their use in making welds.

Flux, as it is purchased, comes in a pulverized form. Owing to the hygroscopic nature of this material, it should be kept in sealed bottles, only enough being mixed for immediate use. The flux is mixed with distilled water in a porcelain dish to the consistency of a thin paste and is applied to the seam and to the wire with a small brush. It is usual to slightly preheat the seam so that the water in the flux will evaporate when applied, leaving the dry powder in place.

Sheet material can be joined by a butt weld, a flange weld, a lap weld, or by some combination of these welds. The flange method is the most common one employed, and consists of bending up the edges to be joined with a flange about three times the thickness of the material, and burning down the flange into the seam. In using either the butt weld or the lap weld the filler rod furnishes most of the material for the joint. In joining fittings to tanks the filled type of weld is usually required.

The preparation of the work for welding starts with the layout of the detail parts. Care in accurately laying out the parts reduces the risks of damage. It is one very necessary essential in the preparation that the edges to be joined be clean. This can be done mechanically with a wire brush or steel

wool, or it can be done by immersing the edges for about 30 seconds in a hot caustic solution followed by a rinsing in a dilute solution (10%) of nitric acid, and that in turn followed by a rinsing in hot water.

The various parts of the job are then assembled, being held in place by clamps (a satisfactory clamp for flanged welds consists of a hinge with through bolt). Note particularly that beads about $1/8$ inch deep follow the seams or difficulties with expansion and contraction of the material will result. All parts being carefully cleaned to form close contact along the seams, the work is ready for tack welding.

Aluminum alloys should be welded with a neutral flame. An excess of oxygen will cause the formation of oxides which cannot be controlled by any flux. It is better to use an excess of acetylene than to run the risk of having too much oxygen. The pressures usually worked with are 15 lb. on the acetylene tank, and 30 lb. on the oxygen tank. Having a neutral flame, the white inner cone should be kept away from the metal about $1/8$ inch and the torch inclined on an angle of about 30° . The operator should endeavor to develop as light a torch as possible and must always be alert for any signs of metal falling away due to the application of too much heat. The forehand method is believed to be preferable to the backhand process. In this method the welder points his torch to his left and works from right to left, the flame preheating the material in advance of the weld.

The job being ready for tack welding, the filler rod is slightly heated and flux applied to the wire. No flux is put on the seams at this time. The torch is then applied to the seam between clamps and the tack welds made, the rod being used to furnish flux and to puddle. Tack welds are made at about 1-inch intervals. Clamps are removed. The seam is then thoroughly cleaned by means of a wire brush. The flux is then applied to the seam on both sides and to the rod. To make the weld, the torch is played directly on the seam, moving it back and forth over a distance of about 8 inches until the flux begins to flow. From this point on, the method is the same as that used in joining sheet steel, excepting that a great deal more care is necessary with aluminum to maintain good fusion and to agitate the molten metal with the wire so that the oxide film is broken.

Constant attention and a great deal of practice is essential to determine exactly when the metal is molten, on account of the short temperature range between the melting point and the point where the material burns and pulls out. The determination of the correct amount of heat to apply is a matter of experience and practice and cannot be adequately described to be of benefit to the inexperienced.

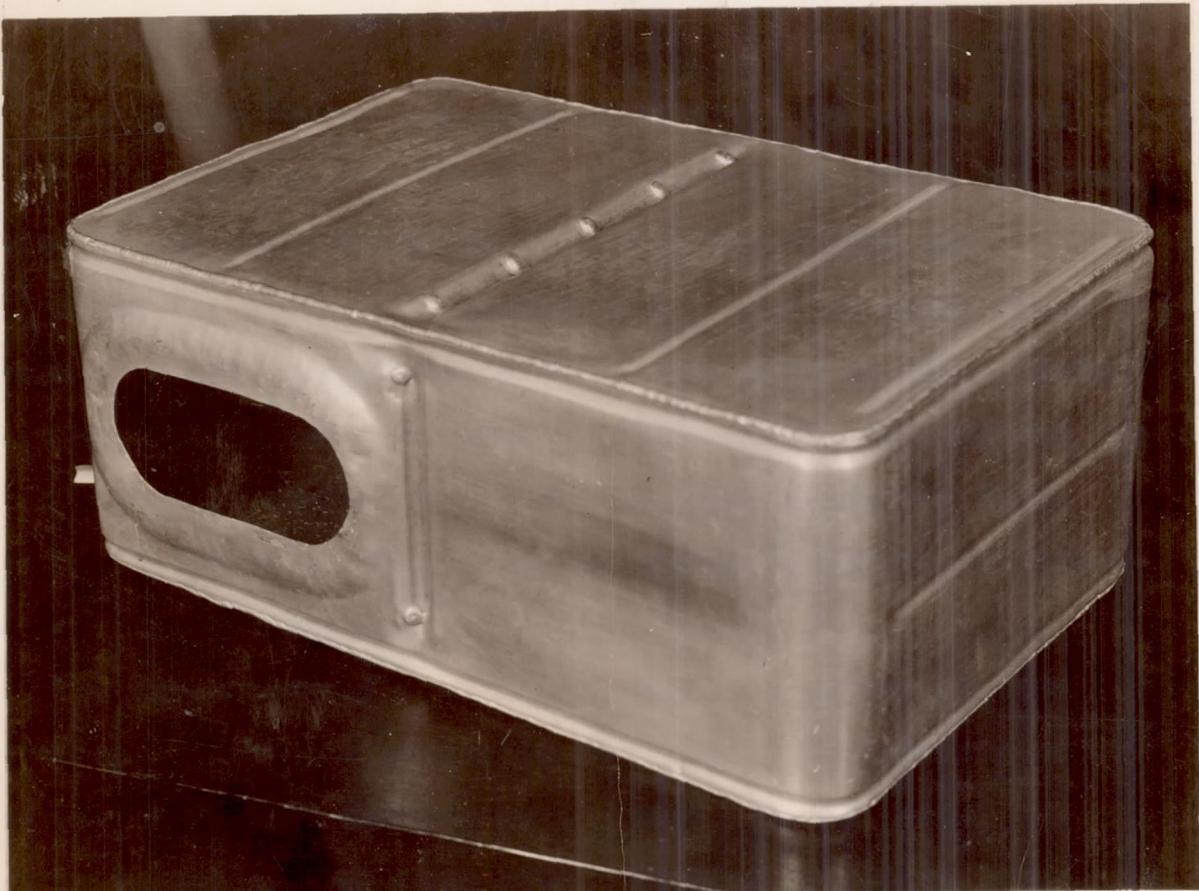
Seams in aluminum castings which are to be welded, are prepared by cutting away the edges on an angle of about 45° . The casting is then preheated at a temperature of about 500°F , and

the welding rod melted and puddled into the seam. To weld a cast fitting to a sheet, the fitting is first tack-welded and then welded to the plate by filling in with the filler rod.

After the welding is completed the part or parts should be washed in a dilute solution of sulphuric acid or nitric acid and thoroughly cleaned of welding flux. Wire brushing and dressing of the weld are effective in removing the excess flux. Rinsing in hot water is a final essential to remove all traces of the acids and salts.

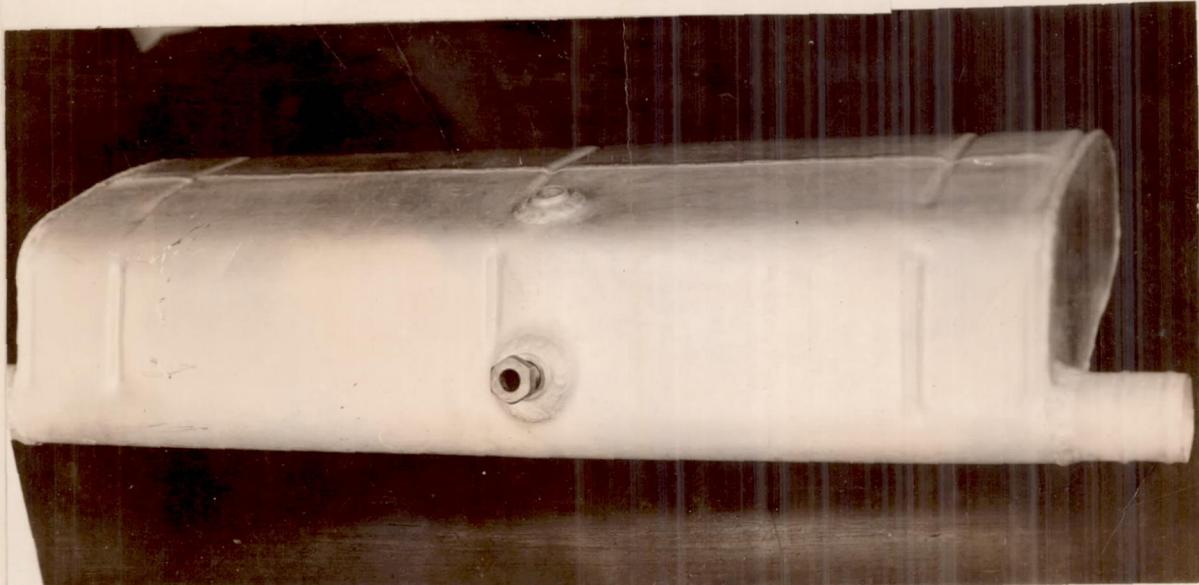
The inspection of a weld can only be a matter of visual examination without subjecting it to a test for tightness under pressure or without destroying the part. Tanks, etc., can readily be tested under pressure. Etching of welded parts in a hot caustic solution will reveal cracks in the metal. The common faults with welds can as a rule be located by a visual examination, however; cracks, buckling, burns, inclusions, excess flux, unevenness, etc., are the usual common faults. A good weld gives its evidence in appearance to a large extent.

In conclusion, it might be said that gas welding of duralumin presents to the aircraft builder a ready means of joining which should be taken advantage of, provided the welds are used where fatigue failures and stress failures are not likely to be encountered. Other thermal methods of joining can still be regarded as experimental in so far as duralumin is concerned.



A gas welded rectangular tank

EXAMPLES OF WELDED DURALUMIN



Fittings welded into a welded duralumin tank of special shape

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